energy technologies institute

An ETI Perspective

Tools for Future Energy Systems

ETI10 TEN YEARS OF INNOVATION 2007 — 2017

INTRODUCTION

Over the last ten years many industries have been through an internet revolution. Shopping, entertainment and keeping up with the news have changed dramatically and companies in those industries have had to innovate and adapt or fail.

The most successful innovations have improved services for consumers by providing greater choice, better information and more competitive prices. There has been a trend towards more active consumer participation, often described generically as "crowdsourcing".

The opportunities opened up by these new information technologies arrive as we face a new challenge to decarbonise energy supply. Providing better information and control has the potential to support this energy transformation helping to make it attractive to consumers, cheaper and lower risk.

KEY HEADLINES

- Better information and control have the potential to support a low carbon energy transformation, making it attractive to consumers, cheaper and lower risk.
- Energy is much more physical than information. Information technologies will transform energy supply and use, but the dynamics will be specific to the energy industry. We need to translate experiences from other industries thoughtfully.
- We cannot know exactly how decarbonisation of the UK energy system will proceed, but it seems highly likely that electricity will play a much larger role in transport and heating replacing fossil fuels significantly.
- The existing system architecture does not have the capacity to support this transition.
- A national energy system is far more complex than most engineered systems. No single architect can determine the details, which increases the need to employ an architectural framework. The success of the internet points the way for energy.
- Work undertaken by the Energy Systems Catapult for the ETI on prototyping various Home Energy Management functions, designed to present heating in a new way to consumers, shows there is a significant opportunity to engage consumers more in how they use energy.
- Just as local authorities are involved in the planning and development of transport, industry and housing in their areas today, there is a strong argument that local network decisions in future should be integrated into local energy plans.

This Perspective document has been created to introduce 'Energy Systems Architecture Methodology: Enabling multi-vector market design' produced by the Energy Systems Catapult for the Energy Technologies Institute

CONTEXT

Our homes and workplaces are becoming more connected as the revolution called the "Internet of Things" gathers pace. From anywhere in the world some early adopters can already look through their security cameras, adjust their heating system and see how much fuel is left in their car.

Although these technologies are only just starting to penetrate the mass market, they will do so at a pace and in ways that will be surprising and hard to forecast.

Our energy industries have been preparing for this revolution by building a 21st Century metering infrastructure. The UK Smart Meter project will enable the home automation systems of individual customers to manage their energy use in detail.

Currently we only know how much electricity and gas consumers use over a few months. In the future much more detailed data could be available about their specific energy use, temperatures of properties, use of appliances and what is needed when.

Suppliers will be able to use this data to offer their customers equipment and services, providing them with more control over their lives and better services and experiences. This has already happened in the insurance industry where some companies now offer drivers cheaper insurance and feedback on their driving habits, through related technologies in cars.

It will be up to individual customers whether or not they choose to use these technologies and suppliers will have to make sure they offer real benefits and that concerns over security and privacy are dealt with, or customers will go elsewhere.

The opportunities opened up by these new technologies arrive as we face the challenge of decarbonising our energy supply. Better information and control have the potential to support this energy transformation, making it cheaper and lower risk. However, the supply and use of energy services is different from books, electronics, news or groceries. A wind farm is a lot more expensive than a server farm and the pipes and wires needed to move petrol, gas and electricity to where we use them are more expensive, bigger and more hazardous than fibre optics. Information technologies will transform energy supply and use, but the dynamics will be specific to the energy industry so it is important to translate experiences from other industries thoughtfully.

There are many different views on how to implement the energy transition. We need to find a structured way in which potential technical solutions and the various challenges can be brought together into integrated solutions that work well within a whole future energy system business environment.

It takes time to develop critical infrastructures and work out how to integrate different technologies to produce end-to-end solutions.

KEY QUESTIONS TO BE ANSWERED

One of the great successes of the internet has been the combination of an open and principles based governance model, together with very clear standards and requirements to participate.

As it is both open and technology neutral you can connect different hardware with different software to it, provided you follow the rules and standards. Everyone can innovate within their own box and also connect to others without knowing exactly how the other technology works.

This leads to three questions about how the UK energy system should develop:

- What kind of governance would best enable innovative, competitive and a consumer focussed delivery of energy services?
- What kinds of architecture might be needed?
- How might we make choices that enable the kinds of changes that are required, while managing risks?

The Energy Systems Catapult (ESC) was launched to address these kinds of questions and to provide the skills, tools and facilities to its users for them to develop and test solutions.

The ESC is collaborating with the Institution of Engineering Technology on the Future Power Systems Architecture project to address the first question for the electricity sub-system of the UK energy system.

The ESC is at least in part, addressing the other two questions for the ETI, as part of their contract to deliver the first phase of the Smart Systems and Heat (SSH) programme which seeks to create future proof and economic local heating solutions for the UK. Both activities are still very much work in progress.

During 2017, the ETI has published a number of detailed outputs and data sets from its project portfolio. Work on energy system architectures is not yet complete; however we have decided to publish a key deliverable from the work area that is addressing end-to-end system operation and control. This is to help make an early contribution to the current debate around the three highlighted questions.

WHAT IS AN ARCHITECTURE?

The word architecture conjures up the design for a complex building. Traditionally this has included how it serves its occupants, the components and systems that hold it up, keep out the weather and keep it working. This idea of architecture has now been extended to complex systems like aircraft, railway networks or information systems, including the whole internet.

A national energy system is far more complex than a single building, more like every aspect of a large city, including all the buildings, roads, water and sewerage etc. In such a complex system of systems with very large numbers of sub-systems, no single architect can adequately determine details.

In a single building the architect usually leaves the detailed design of the heating system or the choice of furniture to others, although critical details sometimes receive an architect's attention.

In these very complex systems the architect determines the interfaces, who makes decisions about sub-systems and how issues about integration are resolved. In our cities we need to decide who is responsible for the traffic lights and whether that is the same as managing the railway and bus timetables. Organisational arrangements, rules for ownership and contracts and governance need to be set out.

Just like a city, an energy system has to keep operating while it evolves to meet changing needs and adopt new technologies.

The architecture is therefore open and should determine how change is enabled, otherwise our cities will stagnate and fade. The architect for our building needs to think about its whole life-cycle and multiple scenarios – how will it be operated and maintained, could it be extended or repurposed, what would happen if it has to be cabled differently or the heating system changed as new technologies are introduced, how might fires be fought and people evacuated, and does it need to withstand exceptional weather or earthquakes.

All of these concepts about complex systems design, life-cycle management and adaptation, governance, operation and change can also be applied to energy systems. Indeed our present energy system did not evolve in a chaotic way but through a series of architecture processes that enabled a highly complex and functional system to emerge from millions of individual decisions within frameworks enabled and created ultimately by government but implemented through many skilled people in organisations with reasonably clear roles and spans of operation.

Today the energy system faces challenges and opportunities similar to our building analogy:

- The increasing power of IT suggests that major sub-systems will need to change to take advantage of new opportunities, for example to provide high speed wireless access all around the building.
- The need to decarbonise our economy will require changes to lighting, heating and air-conditioning and maybe to building fabric.
- Changes to the weather may mean that the building might be exposed to more rain, flooding, greater wind-loadings or more solar radiation that could cause over-heating.

At some point the combination of these changes will need the architecture to be revised by a skilled architect, to avoid a series of fixes that don't work together, which cost more and don't perform as well as an effective process with skilled orchestration of different inputs would have produced.

HOW DOES THE UK ENERGY SYSTEM FUNCTION TODAY?

Our current UK energy system is organised around large centralised assets such as power stations and refineries, with the energy distributed to end users. Within this energy system there are a number of sub-systems.

The largest is liquid fuels, such as petrol and diesel for transport. The next largest is gas into heating, industry and power generation (along with other heating fuels). The smallest is electricity into almost everything. Although electricity is only a small part of the total energy used in the UK, it is expensive to produce and distribute, very flexible in its uses and more widely distributed than any other form of energy. Liquid fuels may be distributed to many millions of vehicles and to some homes and factories, but electricity is distributed to almost every building in the UK, as well as traffic lights, street lights and many other important services such as water pumping stations.

A particular feature of electricity is that it is difficult and expensive to store compared to liquid and gas fuels. Supply must also match demand on a second by second basis. This requires much more oversight than the other larger systems (although petrol shortages are not unknown, even in the UK). The UK's electricity and gas systems were both developed under collective ownership and control, starting off with individual companies set up under local authorities and evolving to national state owned and operated systems. At one point the state owned and operated both systems, from mining the coal through to supplying and billing individual customers for gas and electricity.

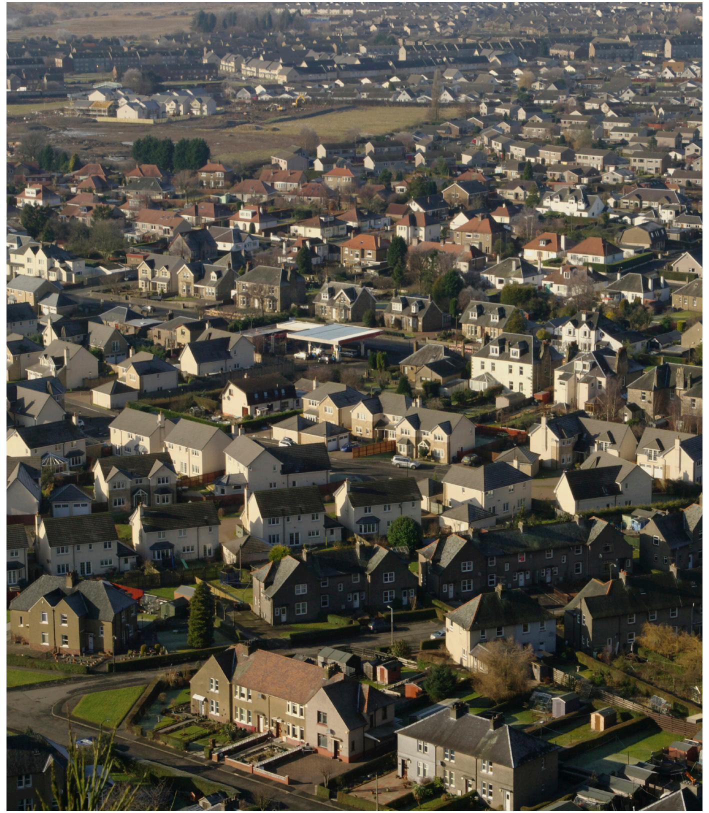
Liquid fuel developed more through private investments in oil and gas production, refineries, stores, pipes and tankers and petrol stations. Indeed the UK does not really have strategic reserves in the way that some other countries do. Nevertheless the state has been intimately involved in its architecture through regulations, inspections, licensing regimes and complex taxation structures at every part of the chain.
We cannot pinpoint exactly how decarbonisation of the UK energy system will proceed, but it seems highly likely that electricity will take a much larger role in transport and heating, displacing fossil fuels significantly.

The existing system architecture does not have the capacity to support such a transition. Electrifying transport and heating will present new and unfamiliar challenges. Also the energy system architecture post privatisation has been operating on a model of incremental investment combined with sweating assets. The blueprint for these assets was determined in a different context, typically one where the state took a leading role.

This is not an argument that the state should decide on all investments but an observation about the governance of the UK energy system up to about 2005. It is now adapting to challenges such as intermittency, opportunities such as Smart Meters and external drivers such as vehicle electrification. There is an ongoing debate about how quickly and effectively it can

respond in its present form, especially given the pressures that will arise from advanced IT in the hands of consumers. As well as different governance structures, new skills and tools will be required.

These pressures have been a challenge for other industries as diverse as retail, print media, photography and finance. Energy will be no different in the level of challenge. In combination with decentralisation through the operation of batteries, smaller generators, heat networks and active appliances, it will be a new, unpredictable world with major opportunities to do a better job than the existing system.



HOW CAN ADVANCED INFORMATION TECHNOLOGIES HELP?

Modern IT systems combine a number of simple elements to produce a revolutionary outcome:

- Low cost sensors that enable many things to be measured – for example all the information that cars now have available.
- Communications infrastructure that enables data to be transported almost anywhere on the planet.
- Relatively low cost storage and processing power that is scalable, so you mostly only pay for what you need.
- Software tools that enable data to be transformed to produce information and insight that can be displayed in a way that people can easily grasp.
- Social and business ecosystems that set expectations and enable us to share and transact without relying on a single point of control. Rating sites such as TripAdvisor, blogs, PayPal and social media channels all provide social and commercial models that increase individual knowledge and empowerment.

These elements have only just started to penetrate energy, which has been held back significantly by the current governance structures. Energy presents similar challenges to those of finance where changes which should benefit consumers come with new risks. However, giving people more freedom in how they buy and use energy should carry less risk than giving them freedoms over their pensions and other investments.

Some commentators are starting to talk about energy "prosumers". To use a finance analogy, they see some people investing in personal pensions and trading in shares on an execution only basis; some people buying into funds (via aggregators, called "asset management companies" in finance) and some people leaving it with National Savings & Investments (NS&I) in a cash ISA.

Work by the ESC for the ETI on prototyping various Home Energy Management functions designed to present heating in a new way to consumers has shown there is a significant opportunity to create greater consumer involvement in their energy use, in ways that most will find very appealing. The data these systems capture will become a major resource to improve the design and operation of energy systems and sub-systems and sharpen competition to provide better services.

Other parts of the energy system will also be improved by IT, including the better monitoring and control of networks and embedding active components such as storage.

HOW WILL KEY DECISIONS BE MADE?

Air travel is another complex system for delivering services to individuals and businesses.

Most of the investments and operations are made by private enterprises engaging directly with suppliers and customers. However, the state ensures that functions such as oversight of safety, air corridor use and traffic management, the allocation of take-off and landing slots and consumer protection are addressed through various means. The state also considers where airports are sited and how they integrate with other transport systems such as road and rail links and the economic and environmental impacts of the whole system.

Energy will continue to combine different mechanisms for shaping and delivering services. Natural monopolies such as networks will still need some kind of regulation or even direct state investment (like road networks) while individual service provision and investments in cars or heating systems will be left to the market.

Consumers will still have wide choices but within limits determined by economics and centralised decisions.

People cannot choose to fly to any destination in the world from any airport. A combination of state led choices about airport siting and commercial choices by airlines determines what flights are available in different regions of the UK. No-one thinks it odd that these choices are location specific. There are similar limits in energy today. For example, the gas network covers most buildings in the UK but not all of them. However, there is sometimes a view that purely private choices could determine the network infrastructure in every part of the UK, while at the same time consumers must have every choice open to them. Just as local authorities are involved in the planning and development of transport, industry and housing in their areas today, there is a strong argument that local network decisions in the future should be integrated into local energy plans. These networks were originally started by local corporations and major changes will need local input. Decisions made locally with the involvement of local residents are more likely to be effective than trying to centralise all decisions on either a technocratic or democratic basis.

In any transition there is always a danger that vulnerable people will suffer, without the risks having been identified or mitigated. Energy is to some extent like housing, health and education where there is an expectation of a minimum level of provision that everyone can access. Cleanliness, comfort, mobility, communication and entertainment are all potentially areas that might be socially underwritten. Existing instruments such as free TV licences and bus passes, winter fuel payments, decent homes standards etc are all signs that energy services come with social expectations.

During a transition risks to vulnerable people should not be identified retrospectively and addressed by fixes, they should be recognised upfront and mitigated by design. This is another area that would require state engagement and governance mechanisms. Fortunately the power of smart consumer IT systems will enable this to happen in a much more effective and targeted way than the current energy system. In principle the state could determine standards of provision and accept competitive bids to deliver them against finely tuned needs. Budgeting and managing performance can be an integral part of such systems.

There are some basic decisions to be made about the construction and delivery of energy services in the UK. State ownership and control of all assets would represent one such decision. Other features of the architecture would flow from that. These kinds of decisions need to be made explicitly and up-front. Uncertainty about the system design would make the risks to all stakeholders unacceptable. The technical paper published by the ESC outlines what some of these might be and what systems might flow from them.

Apart from the elements of the architecture that inevitably require democratically led processes and institutions, every other part can be subject to individual choices based on market led innovation and competition. How far to take this and how to balance the cost and performance advantages of innovation and competition against the risks is still much debated.

Systems engineers tend to agree with economists that intelligent agency is a more effective tool for designing and operating very complex systems than command and control. There is also a strong social trend which is visible in energy to get consumers more engaged. Greater engagement will only come from empowerment, with consumers choosing how and when they access energy services with the supply side becoming more responsive and transparent.

WHAT IS SSH PHASE 1 CONTRIBUTING TO THESE CHALLENGES

The ETI established the SSH Programme and is funding the ESC to deliver the first phase. This consists of work in three areas:

- The design and provision of heating in individual homes, including fabric modifications, heating systems and control;
- Energy planning in individual regions of the UK, especially network choices and investments but including supply chain development, building fabric improvements, social, planning and economic issues;
- System architecture, including new models of service development and delivery on an end-to-end basis and the supporting IT infrastructure requirements.

The technical paper that supports this ETI Perspective is a distillation from a key document from the third area. This is producing a set of conceptual and software tools to support people who are developing and testing alternative architectures. The conceptual tools allow high level examination and the identification of issues and opportunities. The software will also allow testing and validation at a considerable level of detail.

By late summer 2018 the ESC team are aiming to produce:

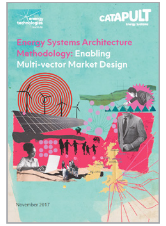
- A model and concept for system architecture
- A set of example business models and a facilitation tool kit that enables people to construct and discuss different ways of designing and delivering energy services, i.e. their own high level business models.
- The first version of a system modelling environment – EnergyPath Operations – that enables the operation of different systems to be evaluated based on their physical, IT, control, business and market model structures and System Operator interventions.
- A library of detailed business processes and interfaces for one example architecture held in a document management and editing tool.

While these tools and concepts might seem unfamiliar within energy they have been adapted from systems engineering practice in other industries.

In order to build these tools around a real example and provide a basis for validation, the team are working on the example of widespread penetration of hybrid air source heat-pumps together with fossil fuel boilers. This is in a full-service or “comfort as a service” environment with a particular transactional and governance environment described in the technical paper. This provides a specific example cross-section across all possible system architectures.

Although this example was chosen because it has some positive features, the main reason was to provide something very different from today with a number of challenging features. This enables the conceptual and software toolkit to be robustly tested and exemplified without the risk of accidental limitations and assumptions being inherited from the current architecture. There is no sense in which either the ESC or the ETI has fully evaluated all the possibilities and chosen this as the preferred solution.

FURTHER READING



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https://d2umxnkyjne36n.cloudfront.net/documents/010200-ESC-ssh-WP3-Future-Report-21-11-2017-7-full-report-Spreads-web.pdf?mtime=20171218105556

Housing Retrofits - A new start

http://www.eti.co.uk/insights housing-retrofits-a-new-start

Consumer challenges for low carbon heat

http://www.eti.co.uk/insights/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat

Decarbonising heat for UK homes

http://www.eti.co.uk/insights/heat-insight-decarbonising-heat-for-uk-homes

Options Choices Actions - UK scenarios for a low carbon energy system

http://www.eti.co.uk/insights/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system/

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